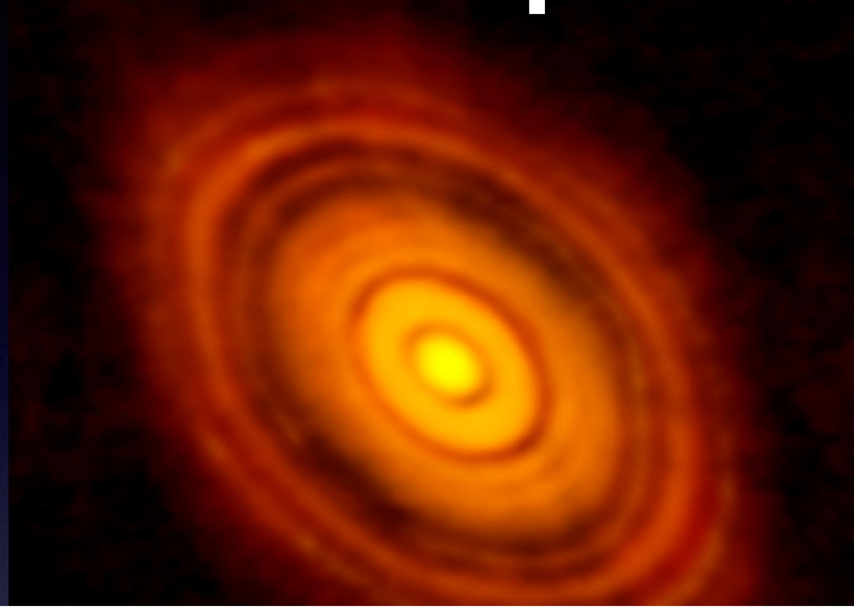
Magnetically Induced Disk Winds and Transport in the HL Tau Disk



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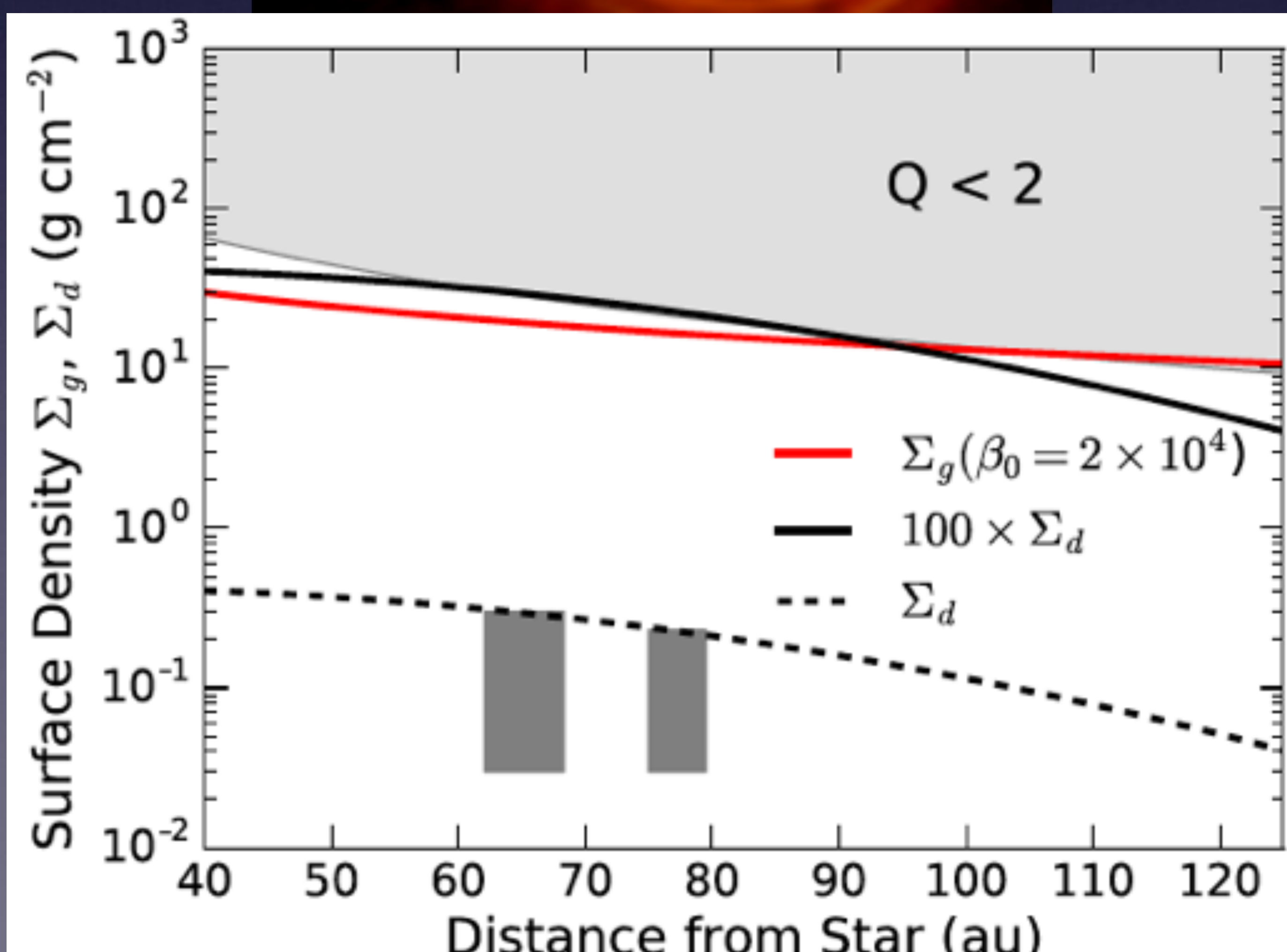


in collaboration with
Satoshi Okuzumi (Tokyo Tech)
Mario Flock (JPL/Caltech)
Neal Turner (JPL/Caltech)

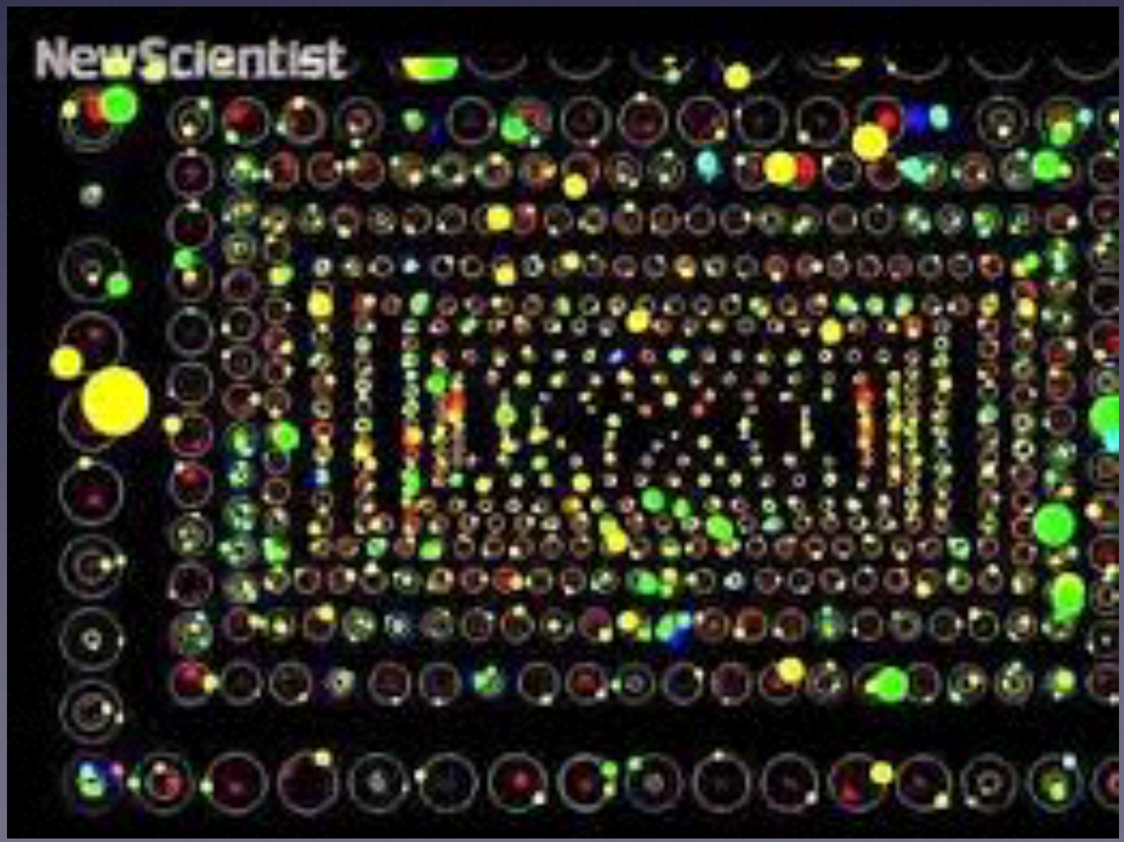
Comprehensive Examination of Planet Formation Covering the Full Size Range

First Stage | **Second Stage** | **Third Stage**

~ micron — ~ mm — ~ m — ~ km — $\sim 10^3$ km — Size

JPL Postdoc -> JPL Scientist

Fill out the Gap in Research between Solar and Extrasolar Systems



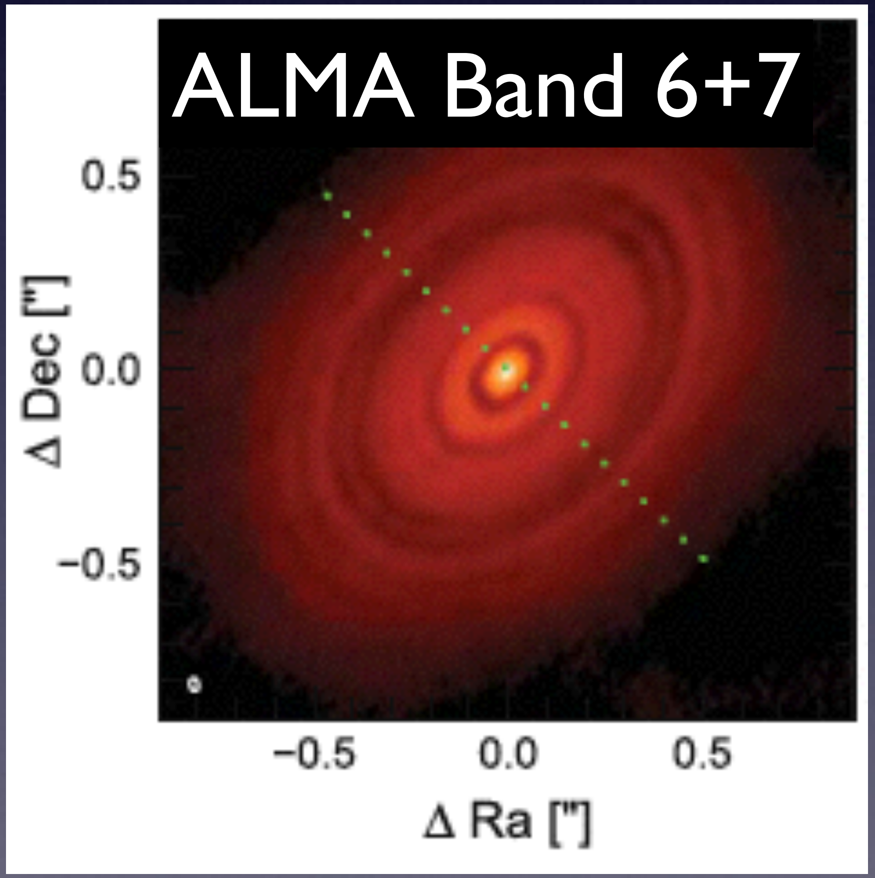
Global Properties of the HL Tau Disk

Disk accretion rate $\simeq 10^{-7} - 10^{-6}\ \mathrm{M_{\odot}\ yr^{-1}}$

Hayashi et al 1993, Beck et al 2010

Global diffusion coefficient : $\alpha_{\mathrm{GL}} \simeq 10^{-2} - 10^{-1}$

=> can be explained by MRI and MHD turbulence



ALMA Partnership et al 2015

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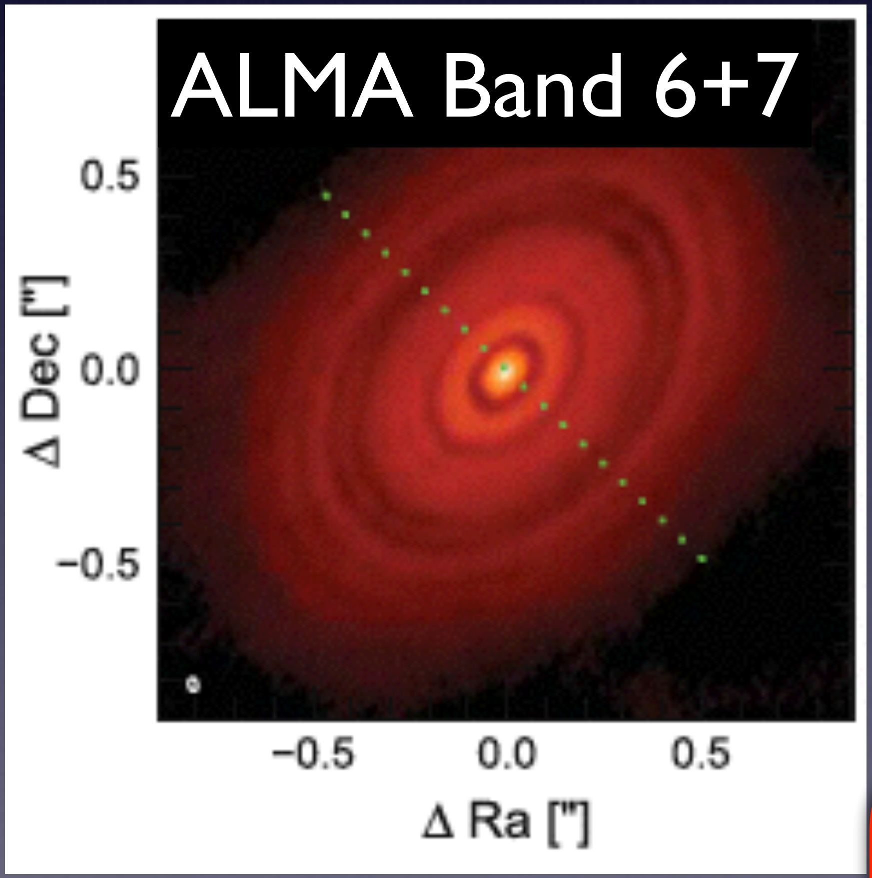
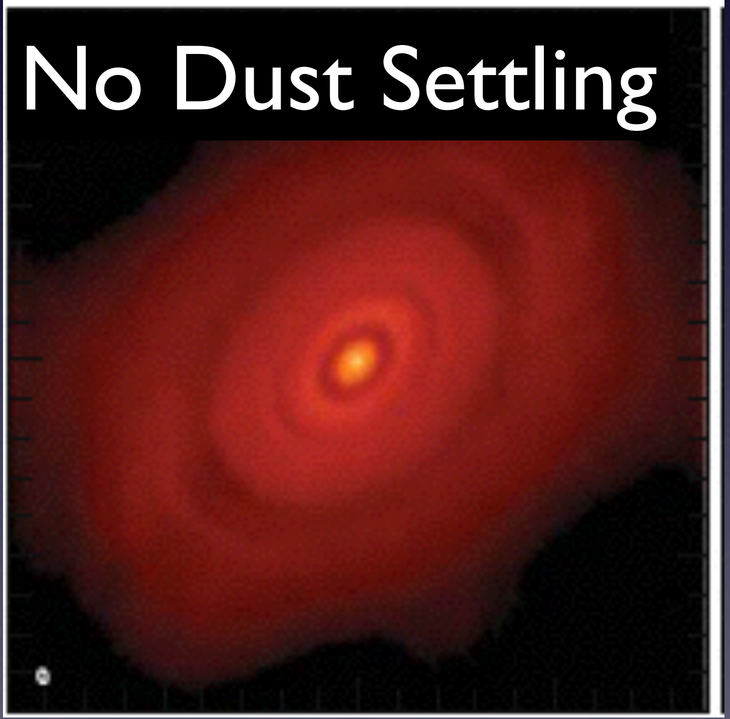
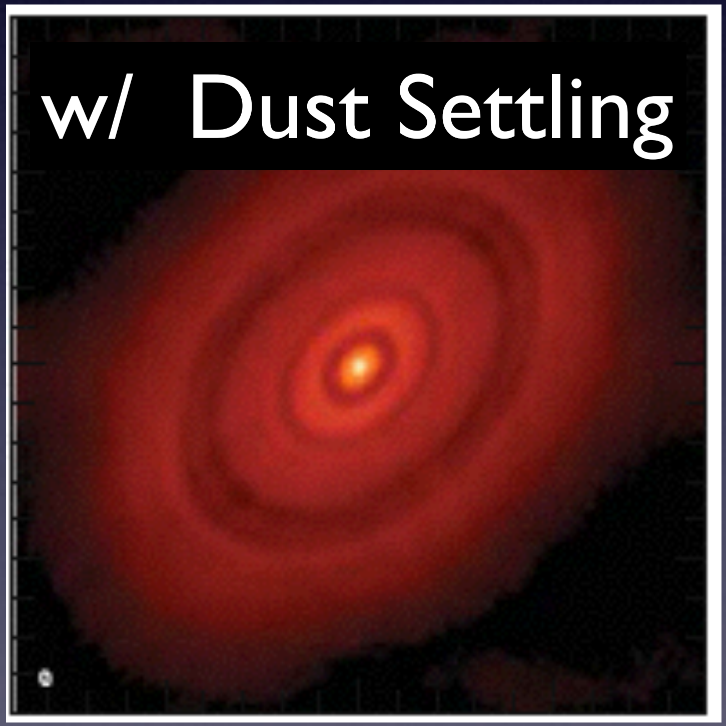






Pinte et al 2016

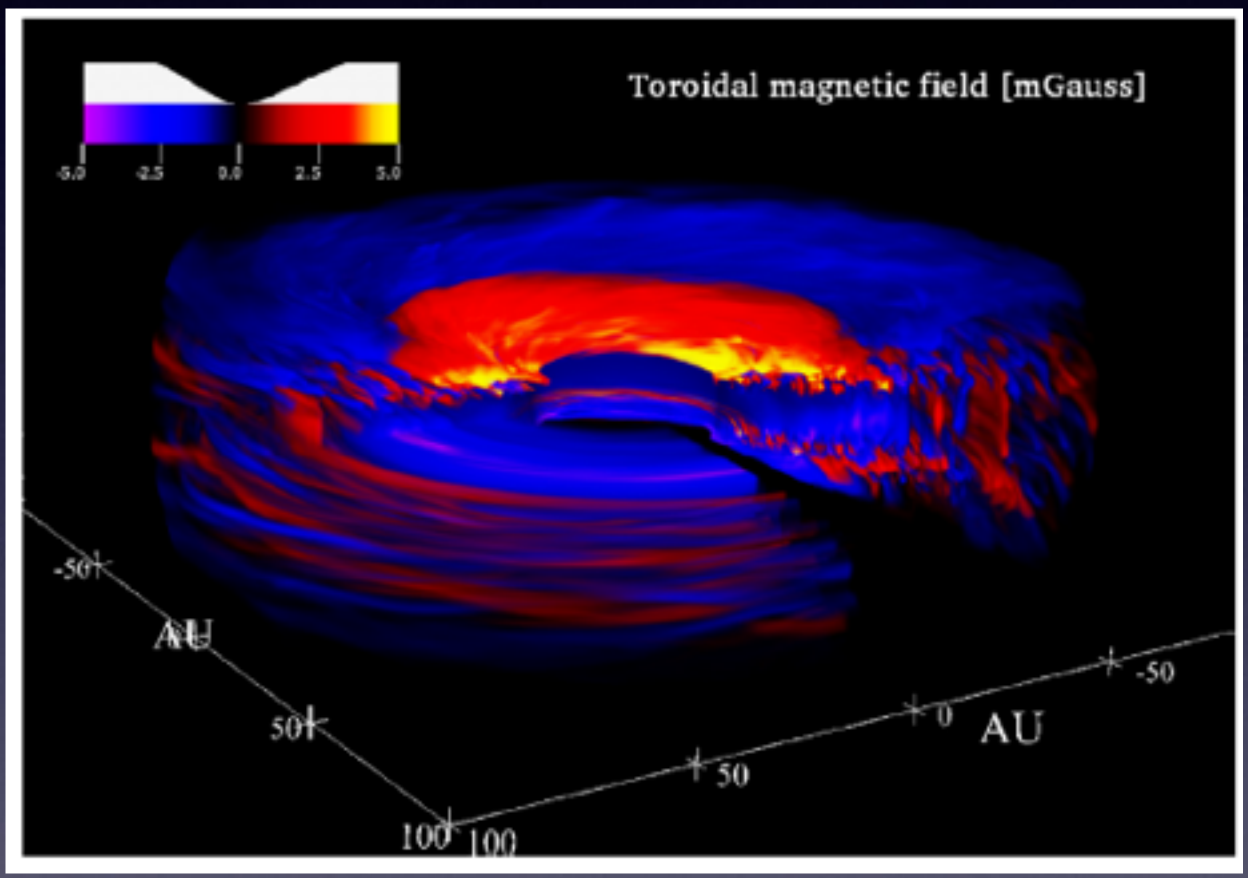
Vertical dust height ~1au at r =100 au

Local diffusion coefficient : $\sim 10^{-4}$

Magnetically Driven Disk Accretion

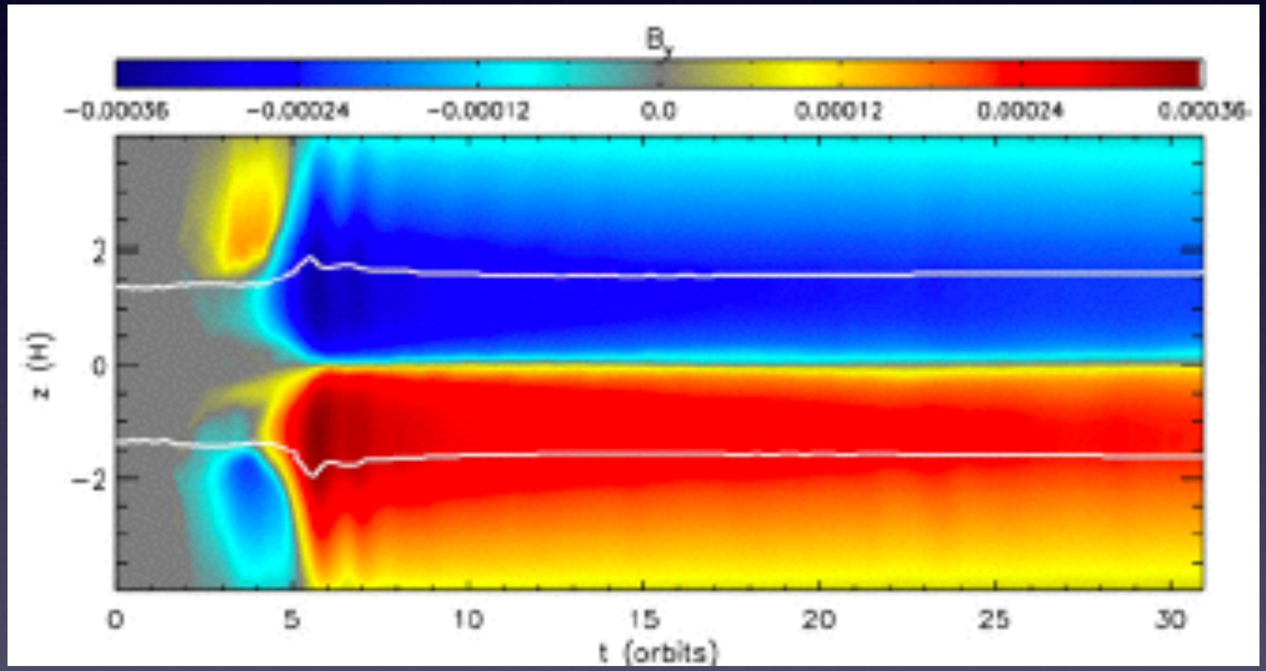
e.g., Armitage et al 2011, Bai & Stone 2013, Turner et al 2014, Suzuki et al 2016

Magnetized Turbulence



Flock et al 2015

Magnetically Induced Disk Winds



Simon et al 2013

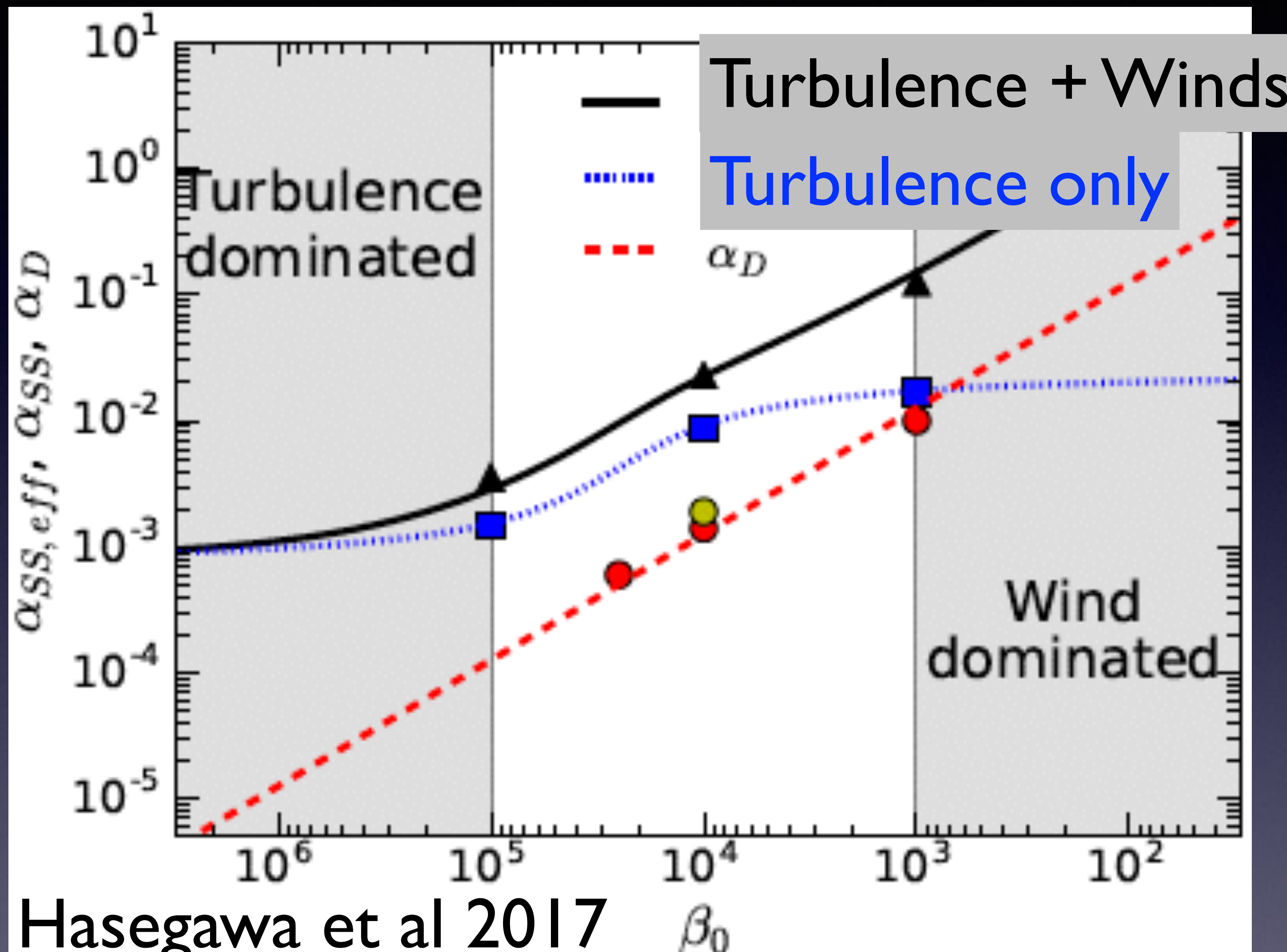
Weak

Strong

B-fields

Magnetically Driven Disk Accretion

e.g., Armitage et al 2011, Bai & Stone 2013, Turner et al 2014, Suzuki et al 2016



α_D : vertical mixing of dust

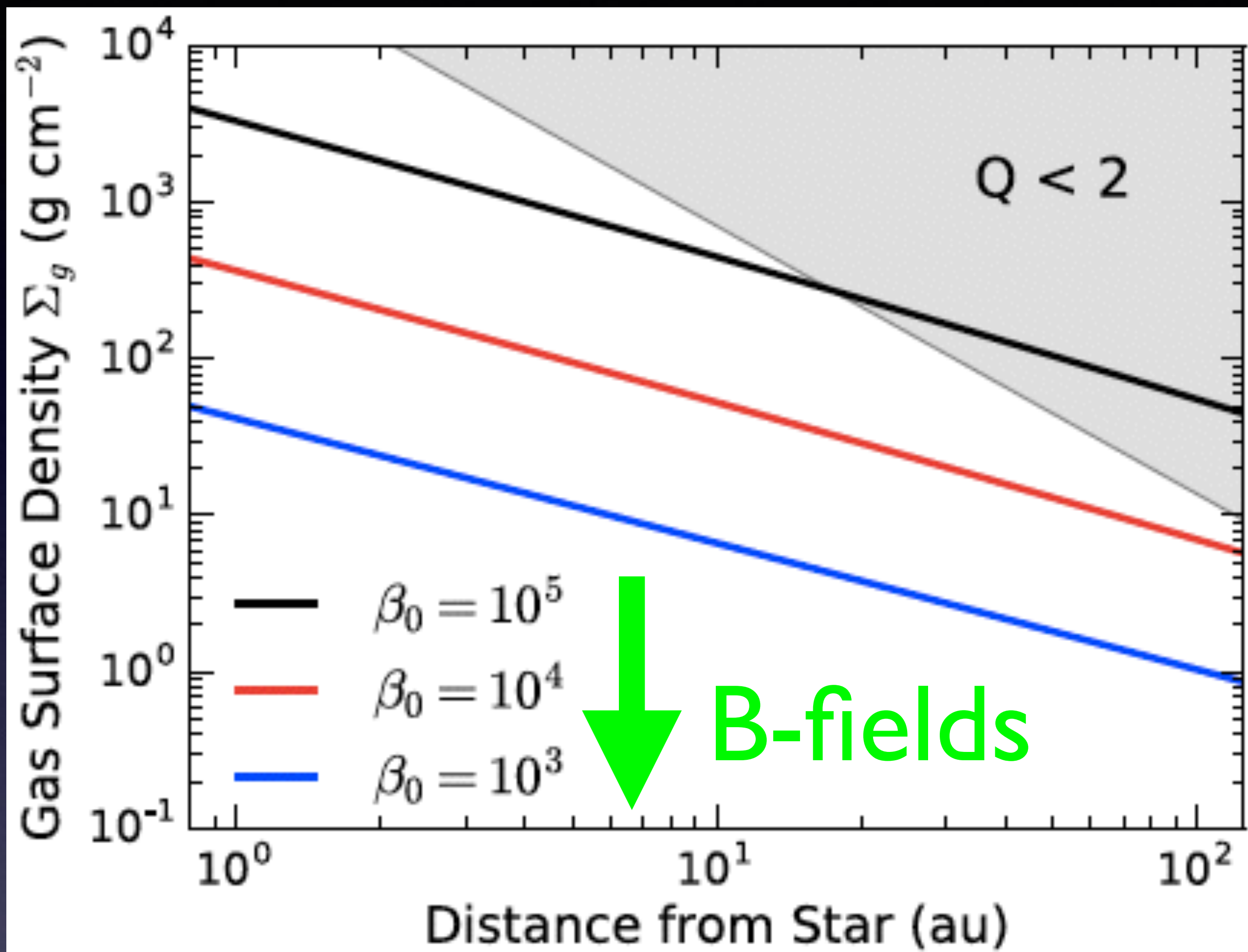
Weak

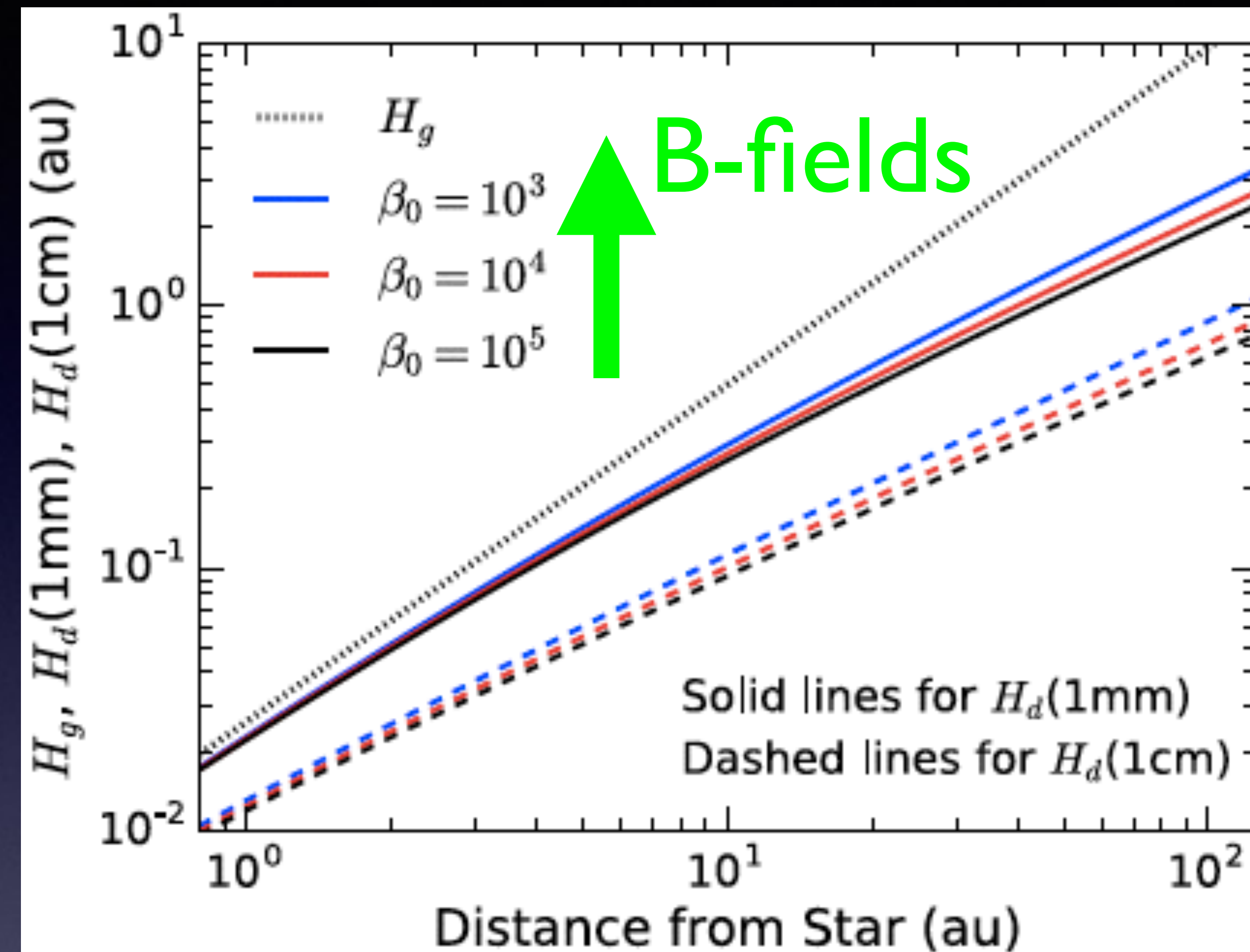
Strong

B-fields

Simulation results from Simon et al 2013, Zhu et al 2015 are used

Resulting Disk Structures





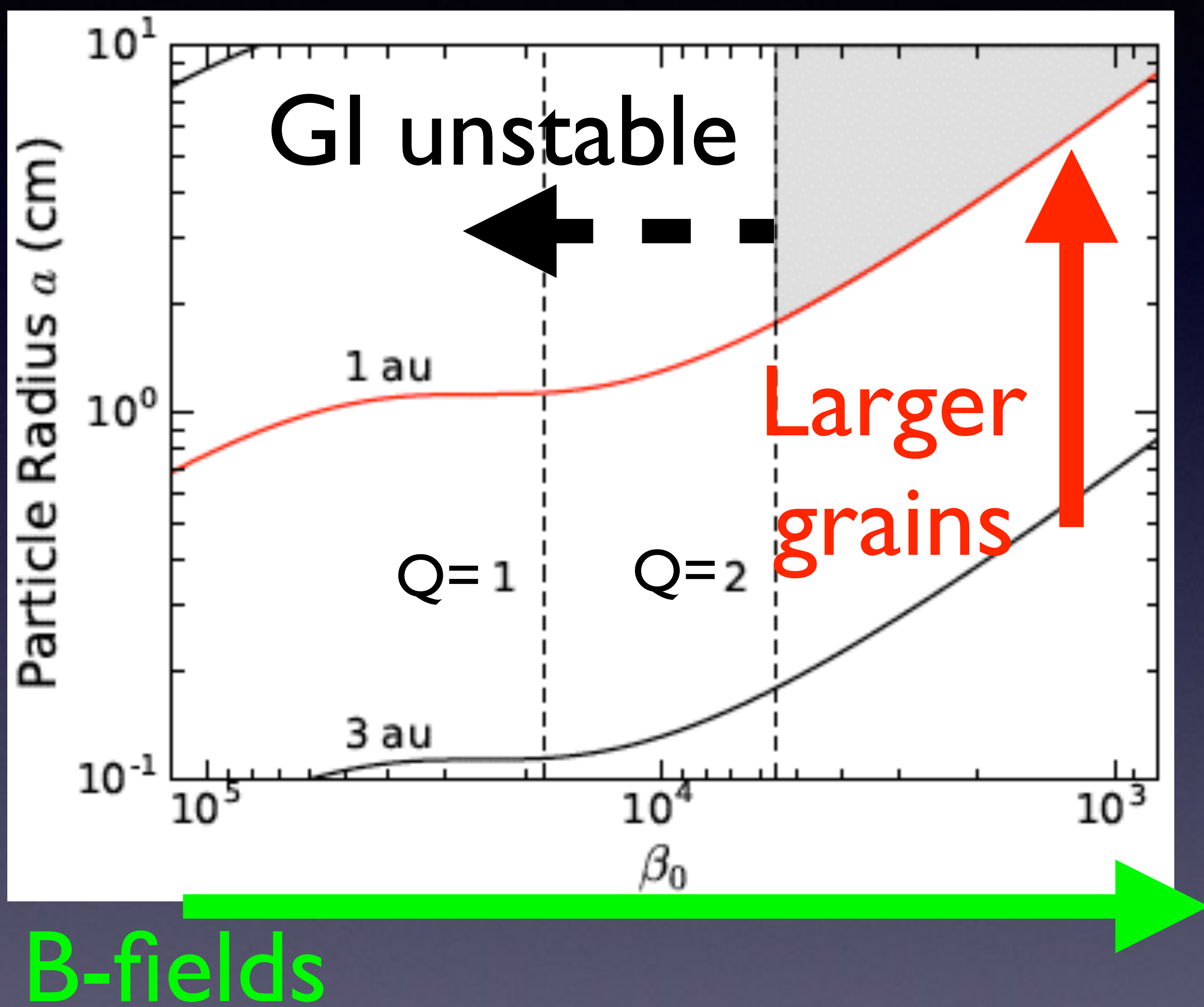
As B-fields are stronger, surface density decreases due to disk winds

Dust scale heights are independent of B-fields

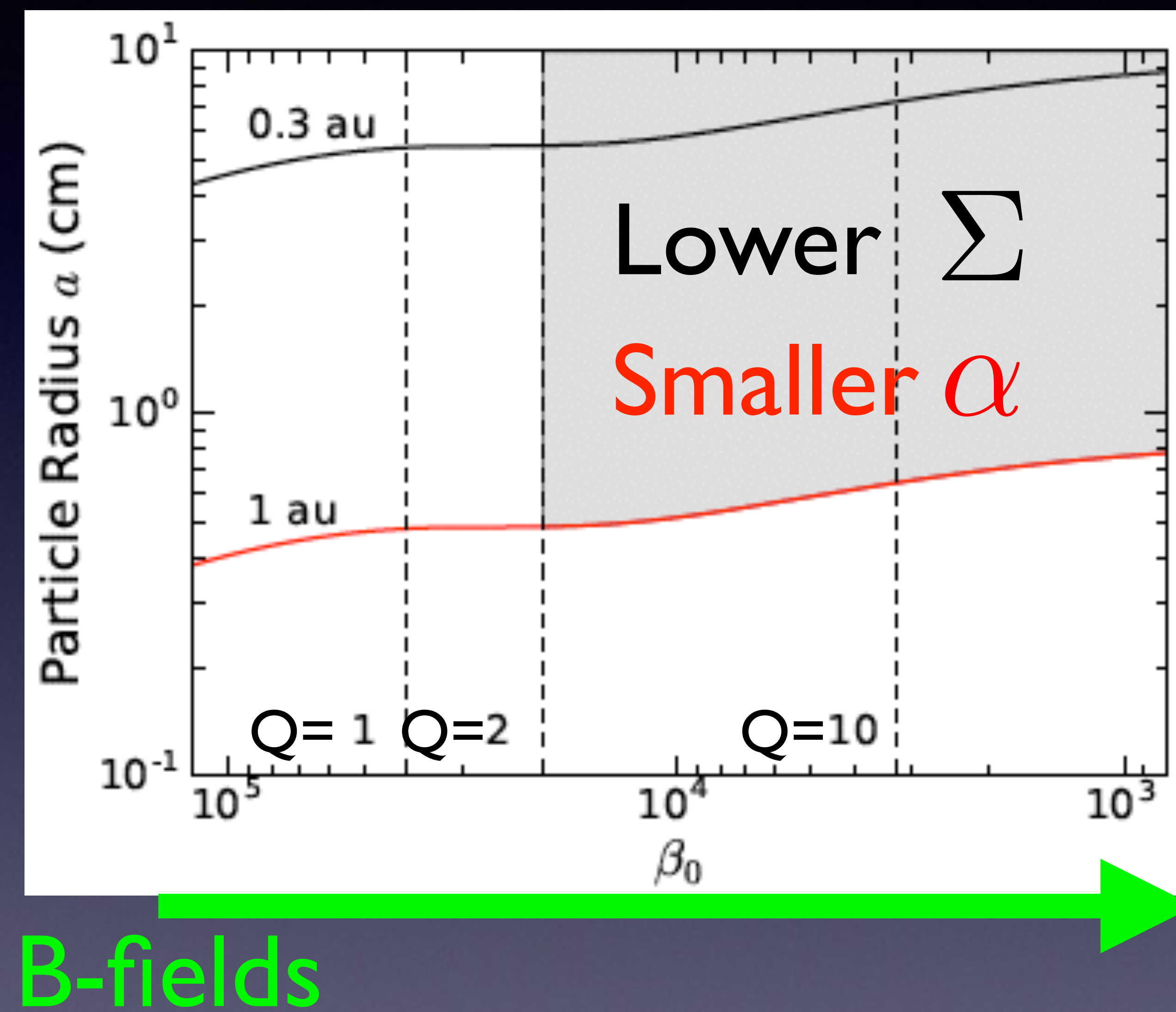
Results are obtained for given values of disk accretion rate, disk temperature

Minimum Size of Dust Particles at r = 100 au

Turbulence only



Turbulence + Winds

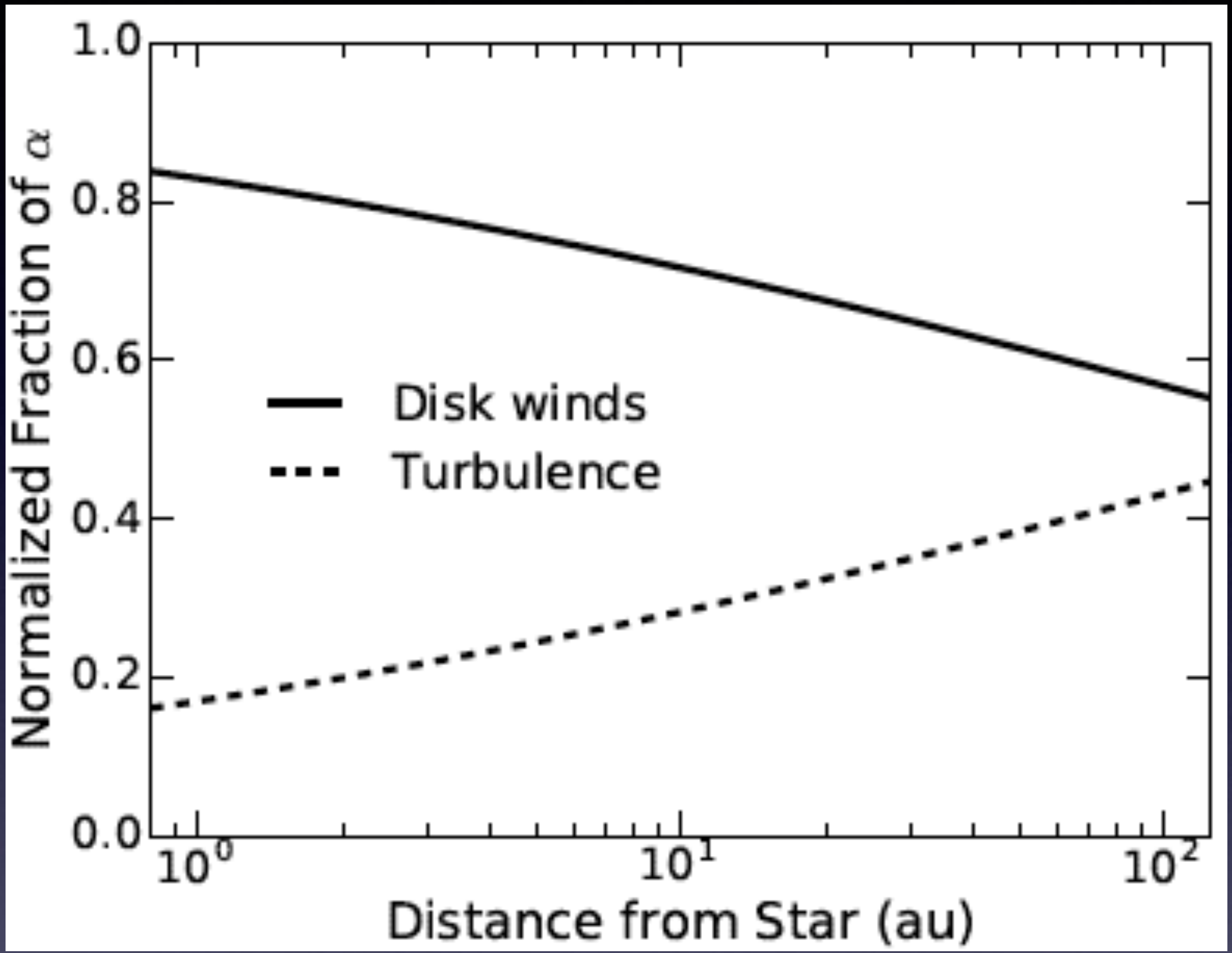


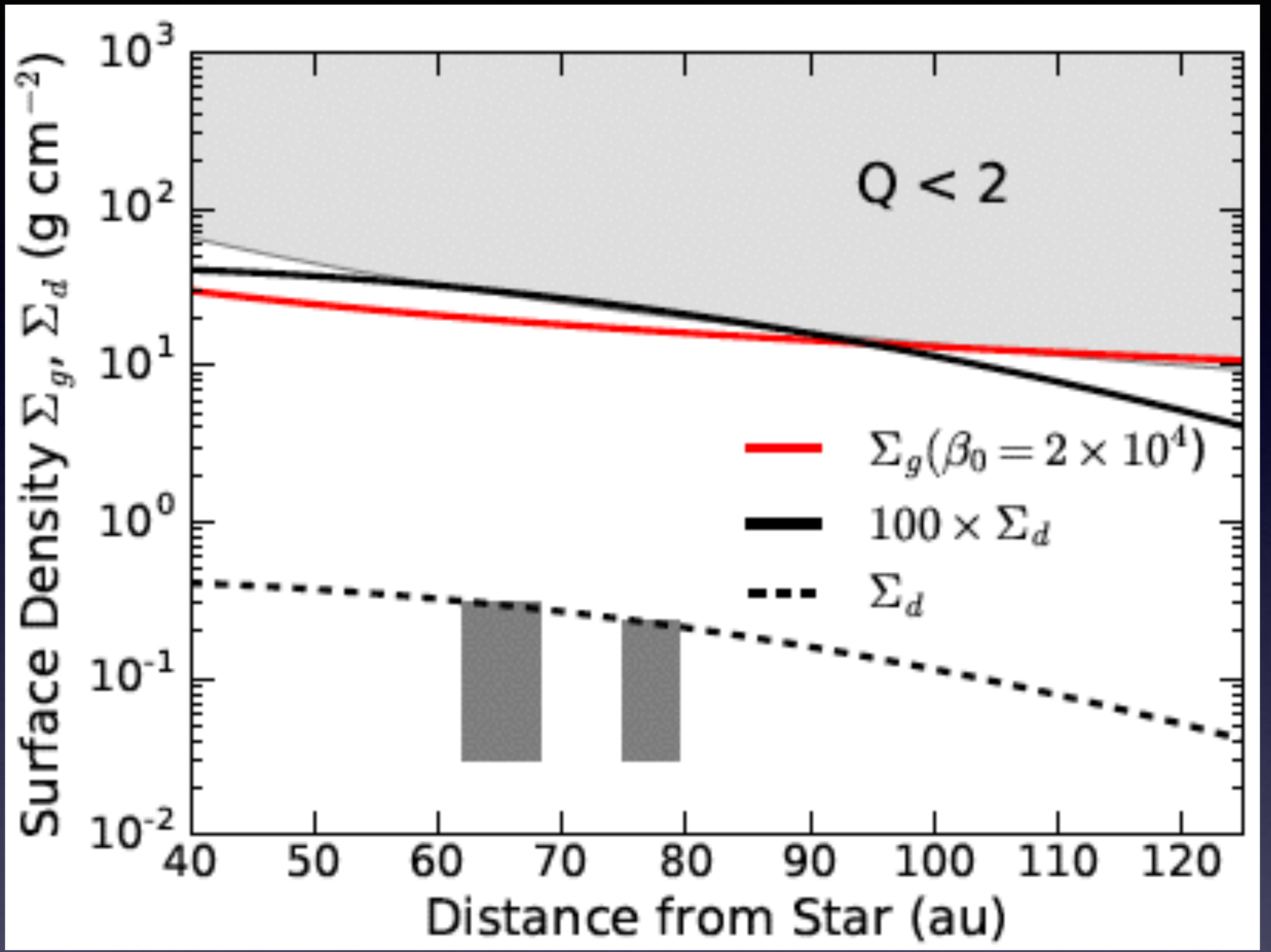
ALMA observes the emission from > 20 mm-sized dust

ALMA observes the emission from > 4 mm-sized dust

Results are obtained for given values of disk accretion rate, disk temperature

Bast Case: Global Structure of the HL Tau Disk





Disk winds transport the most of angular momentum (50-80 %) across the entire region of the disk

The gas-to-dust rate varies along the distance from the star (lower in the inner region & higher in the outer region)

Summary

Hasegawa et al 2017, ApJ, 845, 31

- ALMA observations of the HL Tau disk can advance our understanding of disk evolution
- The Subsequent radiative transfer modeling suggests a higher degree of dust settling for the actively accreting disk
- Developed the simple, semi-analytical model, taking into account magnetically induced disk winds
- Our results indicate the importance of magnetically induced disk winds to fully reproduce the global configuration
- Followup work will be performed to obtain a better understanding of the birthplace of planets and to fully identify the origins of observed multiple gaps in the HL Tau disk